Foreword

National
Oceanic and
Atmospheric
Administration

U.S.
DEPARTMENT
OF
COMMERCE

NOAA Fisheries Service
Northeast Cooperative Research Partners Program

The National Marine Fisheries Service (NOAA Fisheries Service), Northeast Cooperative Research Partners Program (NCRPP) was initiated in 1999. The goals of this program are to enhance the data upon which fishery management decisions are made as well as to improve communication and collaboration among commercial fishery participants, scientists and fishery managers. NOAA Fisheries Service works in close collaboration with the New England Fishery Management Council's Research Steering Committee to set research priorities to meet management information needs.

Fishery management is, by nature, a multiple year endeavor which requires a time series of fishery dependent and independent information. Additionally, there are needs for immediate short-term biological, oceanographic, social, economic and habitat information to help resolve fishery management issues. Thus, the program established two avenues to pursue cooperative research through longer and short-term projects. First, short-term research projects are funded annually through competitive contracts. Second, three longer-term collaborative research projects were developed. These projects include: 1) a pilot study fleet (fishery dependent data); 2) a pilot industry based survey (fishery independent data); and 3) groundfish tagging (stock structure, movements and mixing, and biological data).

> First, a number of short-term research projects have been developed to work primarily on commercial fishing gear modifications, improve selectivity of catch on directed species, reduce bycatch, and study habitat reactions to mobile and fixed fishing gear.
>
> Second, two cooperative research fleets have been established to collect detailed fishery dependent and independent information from commercial fishing vessels. The original concept, developed by the Canadians, referred to these as "sentinel fleets". In the New England groundfish setting it is more appropriate to consider two industry research fleets. A pilot industry-based survey fleet (fishery independent) and a pilot commercial study fleet (fishery dependent) have been developed.
>
> Additionally, extensive tagging programs are being conducted on a number of groundfish species to collect information on migrations and movements of fish, identify localized or subregional stocks, and collect biological and demographic information on these species.

For further information on the Cooperative Research Partners Programs please contact:

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Northeast Cooperative Research Partners Program

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www.nero.noaa.gov/StateFedOff/coopresearch/

NEAR TERM OBSERVATIONS OF THE EFFECTS OF SMOOTH BOTTOM NET TRAWL FISHING GEAR ON THE SEABED

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1.0 INTRODUCTION

1.1 Background

The 1996 Magnuson-Stevens Fishery Conservation and Management Act mandates that regional fishery management councils must designate essential fish habitat (EFH) for each managed species, assess the effects of fishing on EFH, and develop conservation measures for EFH where needed (Auster and Langton, 1999). This laudable objective is a reflection of recent worldwide concern of the effects of fishing on fish habitat, concerns by fishermen upon commercial fish production and concerns by environmentally motivated individuals and groups of effects upon the abundance and diversity of benthic ecosystems for their own sake.

One of the most recent and extensive literature reviews on the subject of fishing gear impacts is that of Auster and Langton presented at American Fisheries Society Symposium 22 in 1999. The review includes 154 references, over half of which were published in the past decade. The authors divided fishing effects into three components: (1) impacts on structural components of the environment, (2) impacts on benthic community structure (abundance, diversity), and (3) impacts on ecosystem-level processes (productivity). All studies reported immediate impacts on resident fauna and a decrease in habitat heterogeneity.

With respect to the first category, a review of 22 studies all showed measurable impacts of mobile gear (i.e. trawls) on structural components of habitat, namely decreased habitat complexity. One series of studies showed tight coupling between loss of emergent epifauna and fish productivity, and a shift in fish species composition to less commercially desirable species along the northwest continental shelf of Australia (Sainsbury 1987, 1988, 1991 and Sanisbury et al. 1997).

With respect to the second category, effects on benthic community structure, these were found to be highly variable and long-term effects were “not easily characterized.” The longest time series studies of fishing gear impacts were conducted in the heavily fished Wadden Sea, and showed “no long-term trends in abundance of 42 common benthic species over 100 years” but found 11 of these species showed considerable variability (Reise, 1982; Riesen and Reise, 1982). Factors that confound many of the studies are the absence of truly undisturbed reference areas and natural disturbance and variability in benthic ecosystems. However, some patterns have emerged from these studies. Impacts of fishing gear are least severe and most short lived in communities that undergo periodic disturbance and are dominated by short-lived species. In contrast, fishing gear impacts are thought to be most severe and long lived in relatively stable environments dominated by long-lived species.

Less conclusive evidence is available concerning fishing effects on ecosystem level processes (productivity), leading Auster and Langton to conclude that the “effects of disturbances caused by fishing to benthic primary production are difficult to predict.”

It is clear that for regional fisheries management councils to “assess the effects of fishing on EFH,” more controlled studies need to be conducted, specifically time studies before and after normal fishing activities and specifically for identifiable types of EFH’s.

To date, much of the research on otter trawling induced habitat impacts in the Gulf of Maine has focused on long-term cumulative changes to sand, gravel, or biogenic bottom communities in areas open or closed to fishing activity. Much less is known about the impacts of fishing gear on soft bottom habitats. A recent analysis of quantitative information on fishing gear impacts reported in 39 separate publications was conducted by Collie et al.(2000). Of the 39 publications none were conducted in mud habitat in North America using an otter trawl. Five North American otter trawl studies were conducted in sand, two in gravel, and one in biogenic habitat. The four studies used to assess otter trawl effects on mud habitats were conducted in Europe and the results for mud habitats were not always consistent, i.e. negative impacts to the total number of individuals and species richness was greater in mud and gravel habitats than sand, however when examining the initial response of individual taxa the more negative impacts occurred in muddy sand, sand and gravel habitats and the least impact was observed in mud habitats.

More recent reviews and studies of otter trawling impacts on mud substrate show few to no short-term study impacts on benthic infauna especially for the net sweep and bottom line components of the otter trawl (Sanchez et al. 2000, Johnson 2002, NE Region EFH Steering Committee 2002). In contrast the heavier trawl doors are known to leave furrows in soft sediment that remain visible for several months. These furrows and depressions are known to focus foraging search patterns by certain benthic or demersal consumers along these topographic features (Burrows et al. 2003). More long-term impact studies have revealed some shifts in the benthic biota of mud substrate from repetitive trawling resulting in a community with fewer species and an increase in the number of small polychaetes (Ball et al. 2000), however, not necessarily lower abundances or biomass. The physical effects of fishing gear smooth bottom gear may be inconsequential and, therefore, undetectable in environments where sediments are eroded regularly and the ambient benthic infauna are already adapted to natural disturbance in the form of bed-load transport of sand and the resuspension of fines by tidal turbulence.

1.2 Project Goals and Objectives

The objective of this study was to have fishermen and scientists in a cooperative effort *observe fisheries habitat characteristics before and immediately after repetitive trawling with a smooth bottom net in soft bottom habitat off Scituate, MA, in the western Gulf of Maine.* The study sites are in the Massachusetts Bay region of the Gulf of Maine in about 130 ft of water and are know to south shore fishermen (Locus Map, Figure 1.2-1). They include the *Mud Hole*, an area frequently fished with mobile gear, and *Little Tow*, which is rarely fished with mobile gear. Because essentially all areas that are suitable for soft bottom trawling in this region are already fished, it is virtually impossible to locate adequate treatment and control sites for comparison. Therefore, we were forced to take the next best alternative – paired sites representing an uncontrolled gradient of trawling pressure.

The purpose of the *smooth bottom* trawl is to herd fish in to the path of the net to maximize the catch per unit effort. In contrast, the purpose of the ground gear of a *hard bottom* trawl is to get over irregularities in the substrate. The trawl system used in this study is designed to hug the bottom and is a typical rig used for smooth bottom to catch flatfish (Mirarchi 1998; Figure 1.2-2 from Smolowitz 1998). Impact on the seabed is probably not uniform throughout the smooth bottom trawl system. The *doors* (or trawl boards) are the heaviest part of the trawl system sweeping about a 5 ft wide path. The *ground cables* that connect the net to the doors are steel cable strung with 2.5-inch diameter rubber disks or cookies. The third part of the trawl system is the *sweep* of the net. The sweep is steel chain that is strung with 6-inch diameter cookies. The lower edge of the trawls' netting is attached to the sweep. The trawl system is about 600 ft in width with the spread of the doors about 200 ft during a tow. A component of the study was to try and identify *how impacts vary among components of the smooth bottom trawl system* (doors vs. ground cables vs. sweep of the net).

A summary of the specific objectives of the cooperative research effort were to:

- Characterize essential fisheries habitat in two 'soft' bottom sites historically subjected to different fishing pressure by mobile gear (Mud Hole and Little Tow, Figure 1.2-1) in Massachusetts Bay; and

- Document after six repetitive trawls with a smooth bottom net trawl any measurable levels of change in the habitat components of the two sites. Habitat components measured included:
    - visual and physical characteristics of the sediment surface,
    - infauna,
    - epifauna,
    - water column parameters,
    - and the fish community and their prey.

A number of aspects of the study fell within the fisheries management information needs. In particular the study:

- Conducted fishing industry-supported high-resolution sediment mapping in areas of the western Gulf of Maine.

- Identified biological communities (pelagic, epifaunal, infaunal) associated with the mapped areas and determined relationships between the 'soft' bottom sediment type and these communities.

- Examined and compared commercially important fish species and benthic biological communities in 'soft' bottom habitat in both heavily and lightly trawled sites and how they respond to the impact of trawling with a smooth bottom trawl net.

- Helped define ‘soft’ sediment-prey field associations for managed groundfish species. Current EFH designations are based on presence/absence and relative abundance of each species from historical trawl survey data. Identifying substrate and prey species and their relationship to fish populations is one of the next logical steps in improving EFH designations.

Although this study is just addressing immediate or acute impacts of smooth bottom net trawling in ‘soft’ bottom habitat, the presence of control (“non-trawled”) lanes in the design allows for future studies on the experimentally impacted sites.

1.3 History of the Fisheries at the Selected Sites (Little Tow and Mud Hole) in Massachusetts Bay

Mobile gear fishing began a rapid expansion in New England waters in 1906 when the trawler *Spray* was constructed by a consortium of Boston fish processors. The new technology quite rapidly replaced the existing longline fisheries due to its efficiency and relative safety yet it generated a storm of controversy due to its bycatch of juvenile groundfish and concern over its effect on the seabed.

Mobile gear fishing did not expand as rapidly in the Gulf of Maine as elsewhere due to the rugged, boulder strewn seabed and the lack of navigational and echosounding technologies. It was probably not until the conclusion of the World War II that mobile gear similar to that in use today came into common use in the Massachusetts Bay area. By 1950 a substantial fleet of draggers from Provincetown, Plymouth, Boston and Gloucester regularly fished Massachusetts and Cape Cod Bays and Stellwagen Bank seeking cod, haddock, flatfish and whiting (S. DeBrusk, in press).

The selection of the study sites for this cooperative research project was sparked by the curiosity of fishermen familiar with Massachusetts Bay region. Both the Mud Hole and Little Tow are historic fishing grounds well known to south shore fishermen. Both historically have yielded abundant catches of yellowtail and winter flounder while codfish appeared seasonally during the late fall and winter months. Despite the similarities in catches and geographic proximity, access to these areas is markedly different.

An area such as the Mud Hole, being both more spacious and connected to other large fishing grounds was frequently fished with several boats spending at least one day per week not uncommon. In contrast, the Little Tow, more isolated, smaller and surrounded by rocky areas was fished infrequently. Often it was the venue for a single, end of the trip “kamikaze” tow where the higher risk of net damage was offset by the possibility of a higher catch in fallow ground.

From post World War II through the mid 1970's navigation and bottom sensing remained unsophisticated. Many fishermen relied on dead reckoning or the alignment of prominent landmarks to orient themselves. Electronic equipment such as Loran A, a system adapted from aircraft navigation, had a highly variable precision seldom exceeding several hundred meters while available echo sounders provided no more than water depth and a profile of the seabed. By the early 1980's technology had begun a quiet revolution in the fishing industry. Loran C and subsequently GPS based plotters offered repeatable precision in the tens of meters while, video sounders and sonar provided reliable information on the texture of the seabed both beneath and ahead.

Despite these advances many areas such as the Little Tow remain lightly fished by mobile gear. The enormous pulse of capitalization that accompanied passage of the Magnuson Fishery and Conservation and Management Act (now known as the Magnuson-Stevens FCMA) in 1977 carried an influx of new fishermen into New England. Many of these were fixed gear fishermen who crowded many near shore areas such as Little Tow with gillnets and lobster pots. At times the density of fields of fixed gear created virtual closures that reshaped patterns of historic mobile gear fishing activity.

The 1990's brought yet another dramatic change in the distribution and intensity of fishing effort with the advent of "rolling closures", periodic closures of 600 square nautical mile blocks to all commercial gear types capable of catching codfish. The study sites lie within Block 125 that was closed for 6 months (Oct. and Nov. 2000, and Jan. through April 2001) during the 2000 fishing year - May 1, 2000 through April 30, 2001, and for a subsequent seven months (Oct. and Nov. 2001, Jan. through May 2002) during the 2001 fishing year - May 1, 2001 through April 30, 2002. These closures were timed to coincide with the months of maximum groundfish abundance within the study areas resulting in minimal displaced effort being substituted in the intervals when fishing was allowed. Closures do not apply to "exempted gears" e.g., shrimp trawl and scallop dredge. Scallop dredge gear is used at study sites. Fieldwork for this study was conducted during June and July 2001 when the sites, Little Tow and Mud Hole, were open to groundfishing.

1.4 Project Team

The project team included members of the south shore, Scituate and Marshfield, MA, mobile and fixed gear fishing communities and local consulting scientists with extensive experience working in the Massachusetts Bay region of the Gulf of Maine.

Mr. Francis Mirarchi, president of Boat Kathleen A. Mirarchi, Inc. and owner of the 62 ft dragger F/V *Christopher Andrew*, was the prime contractor for the project and management lead for the fishermen. These fishermen and their vessels included: John Shea owner of the 57 ft dragger, F/V *Yankee Rose* (Figure 1.4-1 and 1.4-2); Scott MacKinnon owner of the 38 ft gill netter, F/V *Lady Irene*, and Troy Dwyer owner of the 72 ft dragger F/V *Andrea J. II* (Figure 1.4-3 and 1.4-4).

CR Environmental, Inc. of Falmouth, MA, was the lead subcontractor managing field operations, data processing, and report preparation. CR Environmental, Inc. has worked closely with the New England fishing community for over 10 years. In 1995, CR was awarded a Fishing Industry Grant (FIG) to train fishermen in the conversion of their vessels' for oceanographic research. One of that grant's training seminars was held in Scituate, MA. Mr. Mirarchi played a key role in recruiting fishermen for the project and provided the F/V *Christopher Andrew* for equipment demonstrations and training. Since that time the F/V *Christopher Andrew*, Mr. Dwyer's dragger the *Andrea J. II*, and other New England fishing vessels chartered by CR Environmental have performed numerous side-scan searches and surveys, water quality surveys, oceanographic mooring deployments, and sediment sampling operations from Maine to New York.

CR personnel supporting this NOAA Cooperative Research project included: John H. Ryther, Jr., oceanographic operations; Christopher Wright, biologist/hydrographer; Andrew Spinale, fisheries; and Charlotte Cogswell, ecologist. Other key technical project personnel included Dr. David Stevenson, now with NOAA/NMFS for fisheries; Dr. Barbara Hecker, an expert in the analysis of marine community structure and quantitative ecology; Dr. Allan Michael, a benthic infauna expert; and Vincent Capone, a biologist and skilled ROV operator.

1.5 Gear Selection

The survey and sampling equipment selected for this NOAA trawl impact study was owned by CR Environmental or fabricated by members of the south shore fishing community. The equipment is designed for shallow (<100 m) bottom habitat mapping, underwater video surveillance, benthic sampling and water quality surveys. It is lightweight, portable, and designed to be used on vessels of opportunity.

Specifically the project equipment included a:

- Dual frequency EdgeTech Model 272 TD side-scan sonar system consisting of an analog towfish with an ACI board, topside computer with digital interface, power supply, and Chesapeake Technology SonarWiz software and SonarWeb acquisition and processing software;
- Portable Benthos MiniRover MKII ROV system with high resolution video and still cameras, and strobe;
- Lightweight custom aluminum towed video sled with miniature color video camera, video lights and navigation interface;
- Ted Young grab sampler with stainless steel frame;
- Seabird Seacat CTD system;
- Trimble AG132 and ProXRS DGPS systems; and

- Coastal Oceanographics HYPACK survey software.

Oceanographic support equipment fabricated by former Scituate, MA, fishermen, Bob Stevermen, including: oceanographic winches with sliprings and conductor cables, hydraulic A-frames, and side-mounted lifting davits.

This gear is relatively low in cost compared to ocean mapping multibeam systems and large remotely operated vehicles (ROVs). Specification sheets are provided in (Appendix A).

1.6 Experimental Design

The impact of fishing gear on soft bottom sea-floor characteristics and benthic communities was examined in two areas, “Mud Hole” and “Little Tow”, historically subjected to differing fishing pressure. “Mud Hole” is more intensively fished with mobile gear, and “Little Tow” has less mobile gear pressure due to its shape and size, and a high density of fixed gear (lobster traps and gill nets).

An initial reconnaissance survey of the study sites was conducted using side-scan sonar on the 100 kHz frequency and the 100 m range scale, and bathymetry using F/V *Christopher Andrew’s* shipboard Koden echosounder and Northstar 951X DGPS to identify homogeneous habitats at each site and to document differences in historic fishing activity.

Four non-overlapping, lanes or belt transects (1000 m x 100 m) were selected within each site: 2 experimental (trawled) lanes and 2 temporal control (not experimentally trawled) lanes (Figures 1.6-1 and 1.6-2). Sampling was conducted both pre- and post-trawling (after 6 trawl passes) along or at random stations on each of the experimental and control lanes.

Sampling conducted on <u>all lanes pre- and post trawling</u> included:
- Continuous video coverage with a towed video sled along an entire lane;
- One hundred meter long ROV transects run perpendicular to a lane at 3 random stations to obtain detailed video coverage for viewing biota and physical trawl impacts and collecting high resolution still photographs;
- Benthic grab samples – 3 replicate grabs at each of 3 random stations on a lane for infaunal characterization (up to 3 analyzed per station; only 72 contracted for) and one grab for sediment grain size analysis; and
- CTD casts at each of the 3 random stations on a lane.

At each site, six repetitive trawl tows were conducted along each of the towed experimental transects. The contents of each trawl were assessed in terms of the type of fish, number and weight of catch and bycatch; and the contents of up to 20 stomachs from the two dominant groundfish species, winter flounder and yellowtail flounder, were collected.

Table 1.6-1. Sampling Design

SITE	MUD HOLE				LITTLE TOW			
Transects	Experimental		Control		Experimental		Control	
Pre-trawling	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
Video sled - continuous	1	1	1	1	1	1	1	1
ROV transects	3	3	3	3	3	3	3	3
Benthic infaunal samples*	3	3	3	3	3	3	3	3
Grain size samples	3	3	3	3	3	3	3	3
CTD	3	3	3	3	3	3	3	3
Post trawling: After 6 tows	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
Video sled - continuous	1	1	1	1	1	1	1	1
ROV transects	3	3	3	3	3	3	3	3
Benthic infaunal samples*	3	3	3	3	3	3	3	3
Grain size samples	3	3	3	3	3	3	3	3
CTD	3	3	3	3	3	3	3	3
After each tow	Lane 1	Lane 3	Lane 2	Lane 4	Lane 1	Lane 3	Lane 2	Lane 4
Fish, bycatch, stomach contents 2 flatfish species	1	1			1	1		
* Three replicate benthic infaunal samples collected at each of 3 random stations on each lane (144 total). Minimum of 1 sample analyzed from each station with additional replicates analyzed at select stations up to the 72 sample analyses contracted for.								

2.0 RECONAISSANCE SURVEY AND SELECTION OF THE STUDY LANES

A one-day reconnaissance survey of the Mud Hole and Little Tow sites in Massachusetts Bay was conducted on June 19, 2001 to help with planning for the July trawl impact study. The primary purpose of the reconnaissance survey was to select locations for the experimentally trawled and control lanes that had homogeneous substrate characteristics. Side-scan sonar, bathymetry, and bottom grab operations for ground truthing were performed off the 62 ft F/V *Christopher Andrew*.

Side-scan sonar operations were performed with an Edgetech 272 TD towfish and the Chesapeake Technology SonarWiz data collection software. Side-scan data were recorded on a removable hard drive and the data backed up on CDs. Eight one-mile survey lines were run at Little Tow and six-one mile survey lines at the Mud Hole. The side-scan system was operated on the 100 m range scale and 100 kHz frequency, and the side-scan towfish was towed 15 to 20 meters off the bottom. Survey lines were run with 150 m line spacing to provide sufficient overlap for producing side-scan mosaics. Using the Chesapeake Technology Sonar Web processing software, side-scan mosaics of the Mud Hole and Little Tow sites were created and exported to ArcView GIS (Figures 1.6-1 and 1.6-2).

Two to three benthic *grab samples* were collected from the Mud Hole and Little Tow with a Ted Young grab sampler to verify the sediment types depicted on the sonar and to get a rapid assessment of the benthic communities present for planning purposes.

Bathymetric data were also recorded along the side-scan survey track lines using the shipboard Koden echosounder and Northstar 951X DGPS. These systems were interfaced to a laptop computer loaded with Coastal Oceanographics Hypack survey software, and a grid of survey lines was created and displayed on the computer monitor. A steering display was also provided for the vessel captain. Bathymetric data were edited using the Hypack program, tidal corrections were applied, and bathymetric contour maps created using Surfer 7 (Figure 2-1).

The side-scan mosaics and bathymetric contour maps were examined and two 1000 m long x 100 m wide experimental trawl lanes and two 1000 m long x 100 m wide control lanes were selected at each study site. Control and experimental lanes were oriented to take advantage of ‘similar’ substrate types in Little Tow and Mud Hole. Areas of finer sediment were chosen for the study lanes within each site, however, bottom characteristics of Mud Hole and Little Tow were not as similar as had been anticipated. The similarity of catches and appearance of the seabed on their depth sounders had led fishermen to conclude that Little Tow and Mud Hole comprised nearly identical habitats. Information provided by the side-scan sonar survey revealed this vision to be incorrect. In reality Mud Hole, the outer, larger, and slightly deeper basin was characterized by softer, silty sediment with a higher ratio of organic detritus and areas of sand and cobble around the periphery. Most features appeared biogenic, and energy imparted by wave and current action appeared weak. In contrast, the shallower and narrower Little Tow appeared a higher energy environment. Little Tow had a more heterogeneous bottom with areas of sand, sand waves, cobbles, and mud bottom interspersed. Soft sediment was confined to the northwestern end of Little Tow and graded to only a thin veneer over coarser material as one progressed southeast. Coarser, sorted material characterized much of the area, and areas of sand waves covering a pediment of shell hash or gravel occasionally intersected the study lanes.

3.0 TRAWL IMPACT STUDY FIELD OPERATIONS AND METHODS

The trawling impact study was conducted from July 11 to July 19, 2001. As described earlier, the purpose of the study was to document the *immediate impact* of 6 tows with smooth bottom net trawl gear on ‘soft’ bottom communities historical subjected to different intensities of bottom trawling. This cooperative research effort involved 10 fishermen and 4 fishing vessels (1 gillnetter and 3 trawlers) from the port of Scituate, MA, and 8 local scientists and oceanographic technicians. Weather conditions during the survey effort were near perfect with light winds and calm sea conditions. The benthic sampling operations were conducted off the F/V *Lady Irene*, trawling from the F/V *Andrea J. II*, benthic dredge operations from the F/V *Yankee Rose*, and geophysical and video survey operations from the F/V *Christopher Andrew*. A log detailing daily activities is provided in Appendix B.

3.1 Navigation Methods

Navigation for the survey operations were performed using each ship’s DGPS or outfitting the vessels with a Trimble ProXRS accurate to within 2 to 3 meters. These systems were interfaced to a laptop computer loaded with Hypack survey software. Identifying coordinates for the start and end points and random sampling stations along the study lanes were logged.

3.2 Water Column Sampling Methods

No bathymetric survey work was performed beyond that conducted during the June 2001 reconnaissance that confirmed the study sites, Mud Hole and Little Tow, were in waters ranging from 120 to 140 ft in depth (Section 2.0, Figure 2-1). To document water column characteristics at the study sites, CTD casts were made before and after trawling at each of the three random sampling stations on each lane with a Seabird SBE-19 Seacat CTD equipped with oxygen and turbidity sensors. Recorded parameters included turbidity, temperature, dissolved oxygen, and salinity.

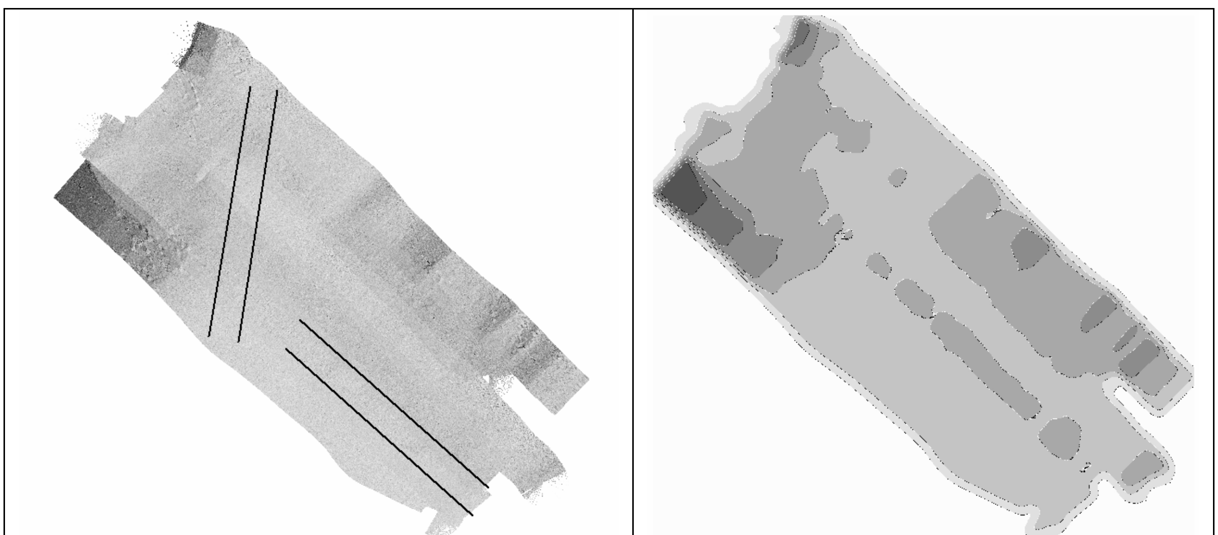
3.3 Side-scan Sonar Methods

High resolution side-scan sonar operations were performed before trawling on July 13, 2001 and after trawling on July 18, 2001 at Mud Hole and Little Tow along each site’s 2 control and 2 experimentally trawled lanes. The purpose of the side-scan surveys was to gather more fine-grained information on the *character of the bottom substrate and to look for evidence of trawl impacts on the lanes*. Surveys were preformed with an Edgetech 272 TD towfish and the Chesapeake Technology Sonar Wiz data collection software (Photograph 3.3-1). The side-scan system was operated at the 50 m range scale and the 500 kHz frequency, and the side-scan towfish was towed 5 to 10 meters off the bottom. Operations were conducted from the 62-ft F/V *Christopher Andrew* captained by owner Frank Mirarchi and a one-man crew. The *Christopher Andrew* was outfitted with a hydraulic winch with a 200 m length of multi conductor coax cable and a slip ring assembly that could support both the side-scan and underwater video sled operations

(Section 3.5). The scientific crew responsible for side-scan operations was John Ryther, Jr. and Vincent Capone.

High frequency *side-scan images* for pre- and post-trawl side-scan sonar passes of each of the eight study lanes (4 control and 4 trawled) were processed using Chesapeake Technology, Inc.'s SonarWeb software. Accurate layback from the DGPS antenna to the towfish was calculated and beam-angle-corrections for each sonar file were made. Sonar data was viewed on-screen at a scale of 1:400 or less, and all observed bottom features that resembled gear-induced marks were digitized.

In addition to producing side-scan images for the lanes, *substrate maps* were produced of the Mud Hole and Little Tow study sites by closely evaluating 100 kHz and 500 kHz side-scan sonar and co-located video data (Sections 3.5 and 4.3), and sediment grain size. The observed properties of the side-scan imagery at these "ground-truthed" locations were then used to estimate substrate types of surrounding areas. While certain substrates on the side-scan sonar data were easily identified (e.g., sand waves), differentiations between "softer" substrates with smooth or flat topography was more uncertain. This is because the representation of the bottom in sonar data is largely determined by the degree of benthic microtopography as well as the reflective properties of different sediment types. Therefore, relatively flat areas of bottom with varying proportions of mud and sand may appear virtually identical. We attempted to minimize the subjectivity of sonar interpretation by using commercial imaging manipulation software (JASC Software, Inc. Paint Shop Pro™) to quantify differences in sonar mosaic pixel shading and contrast. The software's "topographic" effect was used to create a representation of each mosaic with a number of gray shades which corresponded to the number of substrate types thought to be present at each site (see example below).



Side-scan mosaic of Mud Hole	Shaded representation of mosaic

Figure 3.3-1 Example of Image Manipulation Technique Used to Facilitate Substrate Delineations

These images were geo-referenced and imported to ArcView GIS software as image themes. Our initial substrate delineations were created by digitizing the different abutting gray shades. Each of the digitized shades was saved as a polygon theme in ArcView. The shape of each polygon was then adjusted to reflect video and sonar substrate observations.

3.4 Benthic Sampling Methods

Information on *benthic infauna and sediment grain size* was gathered to determine the potential effects of trawling on the benthic invertebrate community which serve as prey for bottom feeding fish in the study area. On July 12, the 42 ft gillnetter *Lady Irene* was mobilized for the benthic sampling operation. The vessel was outfitted with a hydraulic winch, side-mounted davit, sieving table and a Trimble ProXRS DGPS. The scientific crew consisted of Allan Michael, Ph.D. and Christopher Wright assisted by the fishermen, vessel owner, Scott McKinnon, and a two-man crew. Bottom grabs were obtained with a 0.04 m^2 Ted Young modified van Veen grab sampler. Sampling was conducted at three random stations along the control and trawled corridors. At each station, three grabs were collected for the benthic community and one for grain size. Benthic samples were sieved using a 500 micron mesh sieve and stored in formalin (Photograph 3.4-1). From July 12 to July 14, 2001, thirty-six pre-trawl benthic grabs and twelve grain size grabs were obtained from each study site. After trawling the sampling stations were reoccupied, and from July 15 to July 17 an additional thirty-six benthic grabs and twelve grain size samples were collected for a total of 144 infauna samples and 24 grain size samples.

Selected sample stations along the control and experimentally trawled lanes were revisited in August 2001, one month after the initial experiment, to observe any short term recovery of the benthos from any effects observed due to trawl impact in July. Three grabs were taken at each middle sample station along the two control and two trawled lanes in the Mud Hole and one control and one experimental lane (the more northerly lanes with finer sediment) in Little Tow for a total of 18 benthic infauna samples.

In November 2001, fishermen were trained in benthic presorting by Allan Michael, Ph.D. a benthic ecologist at Boat Kathleen A. Mirarchi, Inc. in Scituate, MA. The sieved and preserved benthic infauna samples were transferred from formalin to alcohol and dyed with rose bengal (a protein dye) for presorting by the fishermen. Infauna were sorted by fishermen into vials for crustacea, annelids, mollusks and miscellaneous organisms (Photograph 3.4-2). Sediment residue sorted by the fishermen was saved and checked by taxonomists conducting the final taxa identifications at Allan Michael & Associates lab in Magnolia, MA. Infaunal samples were identified to the lowest practical taxonomic unit and the results for each sample entered into an Excel database as quantitative units. Only 72 of the benthic infaunal samples were analyzed (this is the number of analyses contracted for); at least one from each random station sampled in July before and after trawling and a select number of replicate samples and August samples. The remaining samples are in storage at CR Environmental, Inc.

Grabs for grain size were collected on also processed at Allan Michael & Associates lab. Percent gravel, sand, silt and clay, and the median grain size were determined for each sample on a dry weight basis.

3.5 ROV, Video Sled and Dredge Survey Methods

Two different visual techniques were used to assess benthic habitat and faunal composition. A *video sled* was towed along the experimental (pre- and post trawling) and control lanes (pre-trawling) to obtain broad-scale coverage in both study sites. While this technique provided coverage along the entire study lanes, the vehicle usually moved too fast (>1 knot) to obtain accurate counts of small, cryptic, and/or abundant organisms. In contrast, a *remotely operated vehicle* (ROV) was used to obtain in-depth coverage at specific stations along each of the study lanes (pre- and post trawling). The slower speed of the ROV across the bottom (<0.3 knots) allowed for enumeration of smaller and more abundant fauna, but resulted in much less area being covered. Additionally, the video sled was also used in a drift mode during post-trawling, with coverage that intersected both the experimental and control lanes. These crosstie drifts were added because the ROV footage showed that trawl marks were most easily discernible when approached perpendicular to the direction of trawling. *Dredging operations* were performed post-trawling to obtain voucher specimens for identification purposes and to observe any damage to organisms in the trawl corridors or any general differences in species composition between the trawled and control corridors.

3.5.1 Video sled and ROV operations

Pre-trawl *towed video sled work* at Mud Hole and Little Tow was conducted on July 12, 2001, from the F/V *Christopher Andrew* captained by Frank Mirarchi. The scientific crew for video operations was Christopher Wright, John H. Ryther, Jr. and Barbara Hecker, Ph.D. The towed video sled was equipped with a high resolution Deep Sea Power and Light camera and two 250 watt lights (Photograph 3.5-1). The sled was towed along the bottom at 1 to 2 knots and the camera maintained 1 to 2 feet off the bottom. Video and navigation data were recorded on a topside VCR and displayed on a high resolution color monitor. During the pre-trawl video survey, 1000 m video transects were run along the trawl and control lanes at Mud Hole and Little Tow. During the post-trawl video sled survey on July 19, 2001, the sled was towed only lengthwise along the trawl lanes at each study area and not the control corridors. Instead, four 100 m cross-transect drifts across the control and trawl lanes were performed. These cross-transect video drifts provided better quality video data for discerning the physical trawling impacts. A total of (16) 30 minute video transects were performed with the video sled and a total of 8 hours of video sled footage was collected.

Remotely operated vehicle operations were performed off the F/V *Christopher Andrew* with a Benthos Mini-Rover Mk II ROV equipped with 1000 ft of tether, ultra thrusters, 100-watt lights, and Benthos mini-still cameras (Photograph 3.5-2). The scientific crew was the same as for the video sled survey and Vince Capone was the ROV pilot. For underwater navigation, an ORE LXT short base acoustic navigation system with the Integrated Positioning (IPS) software was utilized and the ROV outfitted with an ORE underwater beacon. This software package integrated the DGPS and acoustic ranges to produce an ROV position to within 5 m. ROV stations were occupied at the three random stations along each control and trawl lanes. Prior to deploying the ROV, the vessel would anchor using a taut single point mooring of a 900 lb railroad wheel anchor. The ROV transects were run perpendicular to the control and trawl corridors for 100 m. During July 14 and 15, twenty-four pre-trawl ROV transects were completed, and from July 16 through 18, twenty-four post-trawl ROV transects were performed at Little Tow and the Mud Hole. Approximately 10 to 15 minutes of video and select still photos were shot at each station for a total of about 12 hours of video.

3.5.2 Video Processing

The video sled footage was viewed on a large projection screen by a team of two people. With the exception of white sea stars and sand dollars, all organisms were counted and identified to the lowest possible taxonomic designation. The advantage of the towed video sled is that it can cover large areas and is frequently moving fast enough to image fish that are attempting to avoid the vehicle. The white sea stars and sand dollars were too numerous to accurately count on the fast moving sled footage. The ROV footage was also viewed on a high-resolution monitor by teams of two people. The slower speed of the ROV allowed all organisms to be counted and identified as specifically as possible. Based on “voucher” specimens, the white sea star consisted of two species, *Asterias vulgaris* and *Leptasterrias tenera*. Juvenile *A. vulgaris* could not be reliably discerned from *L. tenera* on the video footage, so the two species were lumped into the white sea star category.

Underwater video data and audio narration from the ROV and video sled operations were recorded on primary and backup VCR systems. Video screen captures of the underwater video data from the ROV and video sled were created using DAZZLE Multimedia software.

Selected still photographs of representative fish and invertebrate species were also taken with a Benthos Minicamera system on the MiniRover ROV. The photos were recorded on Ectachrome 200 slide film and a subset of the slides was scanned to provide high resolution digital images for the report.

Copies of the video data on VHS tape, and a CD with the video screen captures and still camera images are included with the report.

3.5.3 Experimental dredging operations

On July 17 and July 19, 2001, experimental dredging operations were performed *post-trawling* from the 65-ft bottom dragger, F/V *Yankee Rose* owned and operated by John Shea and supported by a one-man crew. Barbara Hecker, Ph.D. and John H. Ryther served as the scientific crew during the dredge collections (Photograph 3.5-3). A 4-ft wide biological mud dredge with a ½ inch mesh liner was used for the study. Dredging operations were performed to obtain voucher specimens for identification purposes. At each of the bottom grab stations, 10-minute tows were performed. The catch of macroinvertebrates was sorted, identified, counted and representative voucher specimens were stored in formalin.

3.6 Experimental Trawling Methods

On July 15 and 17, 2001, trawling operations were performed from the 72- ft F/V *Andrea J. II* at Mud Hole and Little Tow. David Stevenson, Ph.D. and Andrew Spinale made up the scientific crew, and were supported by the vessel owner, Troy Dwyer, and a two-man ship's crew. At Mud Hole and Little Tow, six consecutive tows were made along each of the two trawl lanes. Completing the six tows and managing the catch along a lane took on average about half a day. *The Andrea J. II's* cod end was outfitted with a 3-inch mesh liner and was operating under an experimental fisheries permit**.** Towing speed was approximately 3 knots. The otter trawl of the *Andrea J. II* consisted of the following components:

- Doors - bison steel polyvalent style doors weighing 350 kg with a spread of approximately 260 ft

- Ground Cables - 240 ft long ground cables with ¾ inch steel cable strung with 2 ½ inch rubber cookies

- Bridles or Legs - 61 ft long top legs of ½ inch-diameter steel cable, and 60 ft long bottom legs of ¾ inch-diameter steel cable with 2 ½ inch rubber cookies. The legs allowed the net to open vertically to about 8 to 10 ft.

- Sweep and Footrope -The sweep extends between the two legs and is the part of the net in contact with the bottom. The sweep was 130 ft long and consisted of ½ inch chain with continuously strung 6 inch-diameter rubber cookies. The footrope is attached to the sweep and was 130 ft in length. Each of the 57.5 ft wings and the 15 ft wide mouth of the net were attached to the footrope.

- Headrope - The headrope located at the top of the net was made of ¾ inch combination rope (polyethylene and steel) and was 100 ft in length.

- Net and Liner Mesh - The mesh of the net was 6 inches, and a 3 inch smaller mesh panel lined the cod end to retain juvenile fish.

Each trawl catch was sorted and weighed by species. Stomachs were removed from up to 20 individuals of 4 bottom feeding target species (winter flounder, yellowtail, cod, and dogfish) from the first, third (or second), and sixth tows and preserved by species and trawl event in formalin. Stomachs were removed at sea on July 15, 2001 immediately following the first two tows in lane 1 at Little Tow. However, fish taken from tow 6 on lane 1, and tows 1, 3 and 6 on lane 3 were kept in the hold on ice overnight and processed the following morning. All fish taken from Mud Hole on July 17, 2001 caught on the 1st , 3rd and 6th tows were processed on board the same day. Total lengths in centimeters were recorded for all cod and for a few randomly selected winter flounder, yellowtail and dogfish from each tow, including those from which stomachs were removed. In some cases, the numbers of individuals caught were also recorded.

For species and tows where total numbers were not determined directly, they were estimated from total weight and mean weight estimates. Numbers per tow for each species were converted to densities (numbers per 1000 square meters) by estimating the area swept during each tow and assuming that all organisms in the path of the trawl were, in fact, caught. Densities were only estimated for bottom-dwelling finfish since mid-water species like spiny dogfish and herring are not very vulnerable to capture in bottom trawls. Neither mean weight estimates nor complete catch in numbers data were available for benthic macro-invertebrates (crabs, lobsters, and scallops), so they were not included either.

Area swept was calculated as:

$$\text{Area} = [(1/2\ (HL + FL))/2] \times TL$$

where HL = headrope length, FL = footrope length (length of the sweep between the wings of the net, excluding the legs and ground cables that extend to the doors), and TL = tow length. For the bottom trawl used on the Andrea J II, the width of the net was 57.5 ft or approximately 17.5 m. Although the trawl lanes were intended to be 1000 m long, actual tow lengths varied from 927 to 1447 m and averaged 1100 m.

Following the experimental trawling, only yellowtail and winter flounder stomach contents were consistently available for the targeted tows. Therefore, subsequent processing of stomach contents focused only on yellowtail and winter flounder stomach samples. Following transfer from formalin to alcohol the collections of stomachs for each sample (i.e. fish species by tow event and study site) were cut open and trained fishermen at BKAM in Scituate, MA, then presorted the stomach contents into vials for annelids, crustaceans, molluscs, miscellaneous taxa and unidentifiable (partly digested) material. The volume of each of these taxa categories was measured with a graduated cylinder using the displacement method. Average stomach volume for a species by tow event was determined by dividing the total volume of the collection of stomach contents by the total number of stomachs in the collection. The sorted stomach contents for each species and selected tow event from Mud Hole and Little Tow were then identified to the nearest taxa. For each sample of stomachs, the abundance of each taxa was categorized as rare (<5), infrequent (>5), common (>30) or abundant (>100) by Allan Michael & Associates Lab of Magnolia, MA.

4.0 TRAWL STUDY RESULTS

4.1 Water Column Characteristics

The bathymetric survey confirmed that the Mud Hole and Little Tow study sites are in about 120 to 140 ft of water. Overall the Mud Hole site is about 10 to 15 ft deeper, ranging from about 125 to 145 ft compared to Little Tow with depths of 115 to 135 ft.

There were no apparent or consistent differences in pre-trawl and post-trawl water quality profiles taken with the Seabird SeaCat CTD during the July 2001 survey. However, due to insufficient cable length for realtime collection, data is not available for depths greater than 100 ft. Stratification was similar at both sites. Temperature generally began to decrease between 10 to 30 feet below the water surface (bws). The thermocline varied from approximately 25 to 45 ft thick with surface temperatures of 16 to 21°C and near-bottom temperatures near 6°C. Surface temperature and thermocline location in the water column appeared to vary diurnally, likely due to solar heating and tidal effects. Salinity averaged about 30 to 33 parts per thousand (ppt). The salinity maxima generally occurred near the bottom of the thermocline and was frequently associated with the dissolved oxygen maxima and minor turbidity spikes. Unedited water quality profiles are provided in Appendix D.

Currents at the study sites are dependent upon wind, waves and tide. Project researchers conducting the ROV survey noted sometimes a knot of current and poor visibility followed in a few hours by lower velocity currents and better visibility. In order to estimate the range of bottom currents likely to occur at Little Tow and Mud Hole, we evaluated available wave height and near-bottom current data.

Data from NOAA mooring 44013 approximately 16 miles offshore of Boston in 55 meters of water should be representative of conditions near the study sites. As shown by Figure 4.1-1, Massachusetts Bay where the study sites are located *had not experienced weather conditions severe enough to result in wave heights greater than 1 meter* for more than one month prior to and during the July 2001 survey, but may experience wave heights above 7 meters during storm events.

Near-bottom current data available from USGS, includes ADCP data from a mooring located about 2-miles off Scituate, MA in 22-meters of water (Butman *et al.*, 2000). Based on a review of the USGS data, near-bottom currents at the study areas *are expected to range from 0 to approximately 50 cm per second* depending on tides and weather (wind and waves). Figure 4.1-2 (below) depicts estimated near bottom wind-driven currents for Massachusetts Bay during a northeasterly storm with wind speeds of 28 knots. Bottom currents in the vicinity of the study sites during such a storm are estimated at about 25 m/sec. It is noteworthy that a moderate northeast gale which occurred over November 16 and 17, 2002 caused a reworking of sand wave patterns at the Little Tow site as observed by side-scan on November 20, 2002, but no visible reworking of the sediment at the Mud Hole.

4.2 Geophysical Results

The study sites, approximately 10 km offshore of Scituate, MA, south of Boston are sediment-draped basins which lie along ridges that are wave reworked remnants of glacial features. Project fishermen had concluded Mud Hole and Little Tow were nearly identical habitats based on the similarity of catches and appearance of the seabed on their depth sounders. Information provided by side-scan sonar during the reconnaissance and trawl study surveys revealed this vision to be incorrect. Mud Hole the slightly deeper and larger outer basin had more soft sediment with little evidence of wave and current action. In contrast, the slightly shallower and narrower Little Tow basin appears a higher energy environment with more coarse, sorted material. At first the diversity seems incongruous but it may well be explained by the interplay of wave and current energy with both bottom features and the proximity of the coastline. During winter storm events, energy from large swells may penetrate deeply enough to disturb the slightly shallower Little Tow basin. Moreover, the surge generated by such storms raises water levels along the coast to the extent that hydraulic pressure generates strong currents that flow offshore along the seabed. Bottom irregularities may focus such currents on areas such as the Little Tow (P. Valentine, USGS, personal communication, March 2003).

The sections that follow describe in detail the substrate characteristics detected at the Mud Hole and Little Tow study sites by side-scan sonar before and after trawling, as well as the results of the grain size analyses.

4.2.1 Side-scan sonar imagery results

Side-scan sonar is capable of differentiating among different bottom substrates and is an effective bottom habitat mapping tool especially when it is used in conjunction with underwater video (Section 4.3). Hard bottom areas such as hard packed sand, shell, gravel, and cobble reflect the acoustic energy emitted by the side-scan sonar systems and appear on the records as dark gray to black images. Soft bottom areas, such as the sandy mud bottom at Mud Hole and Little Tow absorb the acoustic energy and appear as light gray to white images. Rocks or ledge sticking up off the bottom appear as irregular dark images with white acoustic shadows. Bottom depressions in the sediment can also appear as light white records.

Existing Conditions

Figures 4.2-1 and 4.2-2 are side-scan sonar *bottom habitat index maps* of the Mud Hole and the Little Tow sites prior to experimental trawl impacts. On each figure, five areas are noted that represent: hard material, sand waves, flat hard sand, muddy sand, and sandy mud (Mud Hole only). These areas are enlarged to show detailed side-scan images of these representative bottom types in Figures 4.2-1 a-e and 4.2-2 a-e.

Areas 1 and 2 on the Mud Hole and Little Tow figures are harder bottom of sand waves and sand ridges. These produce very characteristic side-scan sonar records. The sand waves appear as undulating dark gray wave crests with white troughs. The sand ridges appear as irregular or jagged dark lines with white acoustic shadows. In the vicinity of area 5 at the Little Tow site, the majority of the bottom is classified as undefined hard material and appears as a dark gray side-scan record. This area is most likely hard packed sand with shell and cobbles but needs to be confirmed with underwater video (video data was collected only along the study lanes at the Mud Hole and Little Tow sites during the 2001 trawl impact study).

Areas 3, 4, and 5 at the Mud Hole, represent muddy sand, flat hard sand, and sandy mud, respectively. The side-scan sonar data shows very subtle differences in amplitude and bottom roughness among these areas, and the records appear as slightly different shades of light gray (Figures 4.2-1 c-e). The only finer sediment category at Little Tow, muddy sand, is depicted in Figure 4.2-2 c (capture 3 on index map).

To further explore substrate diversity at the study sites, bottom habitat maps for Mud Hole and Little Tow (Figures 4.2-3 and 4.2-4) were produced by closely evaluating side-scan sonar and co-located video data. These figures illustrate the greater substrate variability and generally coarser substrate at the Little Tow site compared to the Mud Hole. The seafloor at Little Tow is finer grained to the north and coarser to the south with areas of well defined sand waves. Mud Hole has more uniform, finer sediment that grades to courser material to the north and east. Study lanes were placed in sandy mud or muddy sand except in the southern Little Tow where the substrate was primarily sand at times with shell armor.

Side-scan Evidence of the Effects of Trawling

With the exception of *trawl marks* no detectable changes in bottom characteristics of the study lanes were readily visible in the pre- and post-trawl high resolution sonar imagery. The observation of trawl marks allowed:

- Documentation of the relative amount of 'recent' fishing pressure in the vicinity of the study lanes;
- Documentation of the impact caused by the six experimental tows in the experimentally trawled lanes; and
- Provided confirmation that experimental tows did not impacted the nearby control lanes.

We considered digitized features that resembled gear-induced marks to be reliable qualitative indicators of bottom disturbance by trawling. However, because of the strong influence of sea conditions and towfish position/elevation on side-scan sonar data, we did not attempt to conduct quantitative comparisons of data collected on different dates.

Gear marks visible on pre- and post-trawl high resolution side-scan images of the study lanes were digitized (Figure 4.2-5a and b - Mud Hole pre- and post-trawl, 4.2-5c and d - Little Tow pre- and post-trawl).

Typical images of gear marks in the more sandy sediment of Little Tow versus the finer sediment of Mud Hole are provided below (Figure 4.2-6).

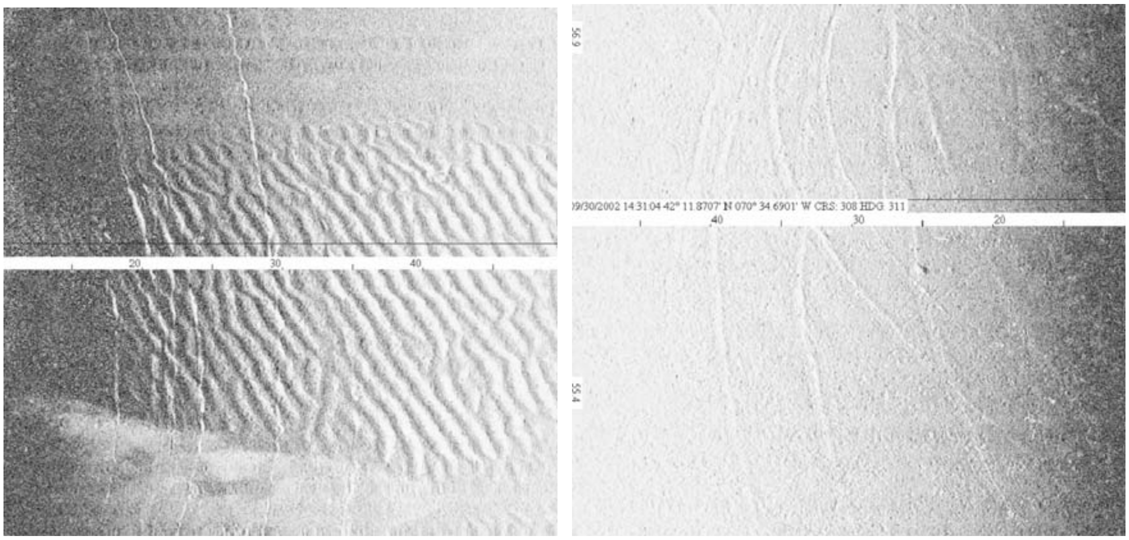
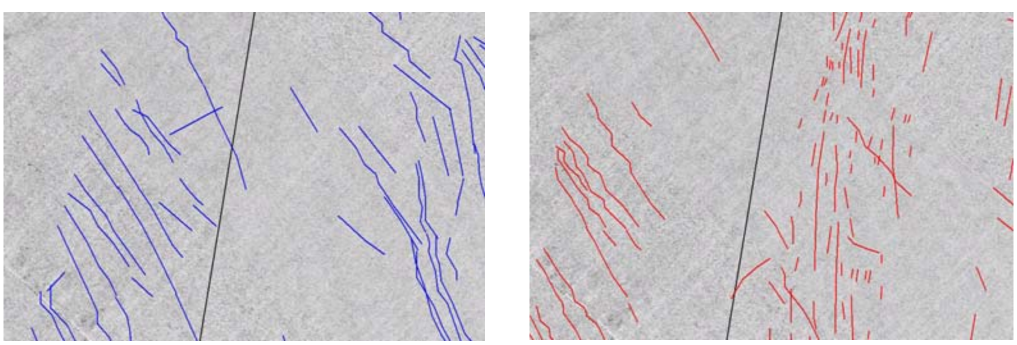


Figure 4.2-6a and b. Side-scan sonar records of gear disturbance to sand (Little Tow – left) and mud (Mud Hole – right)

Pre-trawl gear impacts on the high resolution side-scan images of the study lanes had a prevailing southeast to northwest orientation. In contrast, trawl impacts from our study run parallel to the orientation of study lanes. See pre- and post-trawl images for lane 1 at Mud Hole below (Figure 4.2-7).



Mud Hole Pre-trawl Mud Hole Post-trawl

Figure 4.2-7a and b. Density and orientation of trawl marks at Mud Hole Lane 1 pre- and post-trawl

Side-scan records support the anecdotal reports that Mud Hole is subjected to greater fishing pressure compared to Little Tow (Figure 4.2-5a and c). Before experimental trawling, gear marks were far more abundant at Mud Hole than at Little Tow. Gear marks were also more abundant where the substrate was finer grained. A pre- and post-trawl comparison of gear mark density at Little Tow confirms our video-based observations that the southern trawl lanes, in which the bottom is composed of coarser sand and more shell than the northern lanes, showed fewer and less pronounced gear disturbances compared to the softer northern lanes. Controlling for substrate conditions (i.e. comparing only the northern Little Tow lanes to the Mud Hole lanes) there was still more gear disturbance visible in the Mud Hole lanes (Figure 4.2-5a through 5d).

4.2.2 Grain size analysis results

Existing Sediment Grain Size

Sediments of the study sites prior to experimental trawling were variable, but the modal grain size was typically in the range of *medium to fine sands*. Silt/clay content ranged from 1.6 percent at 45.2 percent. Quartile deviation, an estimate of sorting, was quite high in most cases reflecting the heterogeneous composition of the sediments. With few exceptions sediments at Little Tow were coarser than those at Mud Hole.

On Lane 1 of Mud Hole the sediments got progressively finer toward the south. Station 1A had a mode in the range of medium sand (65%) and a silt/clay content of 9.6%. At the southern end of that lane the modal size was fine sand (37.9%) but there was an almost equal percentage of medium sand (35.9%). Silt/ clay content had increased to 18.4%. Sediments in Lane 2 were consistent with a mode at medium sand (48 to 65%) and silt/clay content ranging from 13.8 to 18.8%.

Lane 3 was predominantly fine sand at the northern end (45 to 54%) but changed to medium sand at the southerly Station C (63%). Silt/clay content was fairly high throughout Lane 3 (18 to 23.7%). Lane 4 had a modal grain size of medium sand at all sites (49 to 68.2%) and silt/clay ranged from 14.9 to 35.2%.

At Little Tow there was a fairly steady progression to coarser sediments from North to South. Lanes 1 and 2 had modal sizes in the fine sand range (30.2 to 47.1%) with silt/clay content from 6.4 to 45.2%. The southernmost stations of Lanes 1 and 2 were predominantly medium sand and all of the sites in Lanes 3 and 4 had modal grain size of medium sand (48.9 to 88.1%). The southeastern sites of Lanes 3 and 4 had very low silt/clay content (1.3 to 2.7%).

Trawling Effects on Sediment Grain Size

The post-trawl grain size results for Little Tow and Mud Hole sediments showed similar overall geographic trends as recorded in the pre-trawl survey, and grain size was still generally finer in Mud Hole. At Little Tow, the northern stations (Lanes 1 and 2) and Station 3A were predominantly fines sand (40.3 to 56.1%). Silt/clay content ranged from 8.3 to 16.8%. Three stations in the southeast corner (3C, 4B and 4C) were medium to coarse sands (49.9 to 63%) with very little silt/clay (1.0 to 1.5%). The post-trawl sediments at Mud Hole had a fairly consistent silt/clay content ranging from 14.5 to 24.1%, with the coarsest sediment in the northern reaches of Lanes 1 and 2. Although the geographic trends were similar in pre- and post-trawl grain size samples, the post-trawl sediments at Little Tow and Mud Hole were of a lower median grain size at many of the sample stations especially those with softer sediment. This trend occurred at both trawled sample stations on Lanes 1 and 3, and non-trawled sample stations on Lanes 2 and 4 (see Figures 4.2-8 and 4.2-9, and the grain size data in Appendix E). The shift in modal grain size was from medium to fine sand. This suggests that either:

(1) The disturbance caused by the study's trawl gear, coupled with unquantified bottom currents, resulted in the resuspension and redistribution of surficial sediment and sediment transport beyond the trawled lanes; or

(2) Differences in the pre- and post-trawl data sets were not due to the effects of our experimental trawling but rather resuspension and deposition due to currents or wave action.

Note that no major storm events occurred between the pre- and post-trawl sediment collection dates of July 12 and 14, 2001 (Section 4.1).

4.3 Remotely Operated Vehicle Video, Towed Sled Video, and Dredge Results

4.3.1 ROV and video sled results

Video of the Existing Seafloor Conditions

Visual observations and side-scan data (Section 4.2.1) indicate that the seafloors at Mud Hole and Little Tow represent quite different habitats. The seafloor at Mud Hole consists of fine-grained sediments that appear to be flat hard sand with shell armor and muddy sand in the northern region, and gradually grades into hummocky flocculent sandy mud in the southern region (Plate 4.3-1). At Mud Hole much of the surface of the seafloor appears to be structured by biological forces. Present are numerous microtopographic features such as tubes, small feeding depressions, mounds, and tracks and trails. In contrast, much of the seafloor at Little Tow appears to be structured by physical forces. The seafloor at Little Tow is muddy only in the northern region and grades into rippled sand and well-defined sand waves in the southern region (Plate 4.3-1). The sandier regions of Little Tow have much less infaunally produced microtopography, such as tubes, feeding depressions and mounds. Additionally, within-region habitat variability (patchiness) appears to be more pronounced in Little Tow (Figure 4.2-4) compared to Mud Hole (Figure 4.2-3).

Nine identifiable species categories of *fish* were observed on the video sled and ROV footage. The 453 fish seen in the towed video sled footage belonged to 7 species (Table 4.3-1, raw video sled counts). The most abundant of these were ocean pout (140 individuals), flounder (121 individuals), silver hake (75 individuals), red hake (64 individuals), and sculpin (48 individuals). Additionally, four skates and one sea raven were also seen. The 182 fish seen in the ROV footage belonged to 8 species (Table 4.3-2, raw ROV counts). The most abundant were ocean pout (58 individuals), sculpin (41 individuals), red hake (39 individuals), and flounder (25 individuals). Five silver hake, 4 dogfish, 1 monkfish, 1 sea raven, and 8 unidentified fish were also seen. Plate 4.3-2 contains video screen captures and Plate 4.3-3 high resolution still photographs of fish species observed at the Mud Hole and Little Tow sites. The two video techniques resulted in different proportions of at least two of the fish species. Silver hake and flounder comprised greater proportions of the fish seen in the towed video sled footage (16.8% and 26.7%, respectively) than in the ROV footage (2.7% and 13.7%, respectively). This difference is quite likely attributable to the faster speed of the towed sled allowing us to image fish that exhibit avoidance behavior. The silver hake usually rested in depressions on the bottom until the vehicle was several feet away and then rapidly swam away. Flounder also exhibited similar avoidance behavior. In contrast, ocean pout, which exhibited much less avoidance behavior (frequently only lifting off the sediment briefly as the vehicle approached), were found in comparable proportions in the footage obtained from the two vehicles (30.9% and 31.9%, respectively).

Sixteen identifiable *invertebrate* species were seen on the video sled and ROV footage (Plate 4.3-4, and still photographs Plate 4.3-5). White sea stars and sand dollars were by far the most abundant invertebrates seen. The 9,256 invertebrates counted on the ROV footage belonged to 13 species categories. The most abundant of these were white sea stars (consisting of *Asterias vulgaris* and *Leptasterrias tenera*) which accounted for 8,492 individuals and sand dollars which accounted for 555 individuals (Table 4.3-2). Of the remaining 209 invertebrates seen in the ROV footage, 110 were *Cancer* crabs and 47 were sea scallops. A similar pattern was seen in the towed video sled footage. The sea stars and sand dollars were too abundant to be enumerated in this footage, but of the 414 invertebrates counted 266 were *Cancer* crabs and 88 were sea scallops (Table 4.3-1). All 16 invertebrate species were seen in this footage.

Habitat differences between the two study sites were reflected in the benthic megafaunal community. The video sled data indicated that both fish and invertebrates were more abundant in Mud Hole than in Little Tow (Figure 4.3-1 bar graph). Fish observations ranged from 1.63-2.04 individuals/minute in Mud Hole and from 0.79-1.48 individuals/minute in Little Tow (Table 4.3-3), with red hake, silver hake, sculpin and flounder accounting for most of the difference (Tables 4.3-4 and 4.3-5). Invertebrates ranged from 1.40-2.27 individuals/minute in Mud Hole and from 0.58-1.00 individuals/minute in Little Tow. Most of the difference in the number of invertebrates between the two areas reflected a difference in the number of *Cancer* crabs, with 1.30-1.80 individuals/minute in Mud Hole (Table 4.3-4) and 0.00-0.68 individuals/minute in Little Tow (Table 4.3-5). In contrast, sea scallops were more abundant in Little Tow (0.29-0.52 individuals/minute) than in Mud Hole (0.07-0.30 individuals/minute). The differences in faunal density between the two areas can best be seen in maps showing fauna observed along the video sled survey lines. Faunal density was much higher throughout Mud Hole (Figures 4.3-2 and 4.3-3) than it was in Little Tow (Figures 4.3-4 and 4.3-5). A closer examination of the faunal symbols on these maps also shows that many of the species are patchily distributed within the sites. One example of this patchiness was seen in the distribution of silver hake (dark green square), which were particularly abundant in the southern end of Lane 1 in Mud Hole (Figure 4.3-2).

Similar faunal differences between Mud Hole and Little Tow were also seen in the ROV survey (Table 4.3-6). Fish tended to be more abundant in Mud Hole (0.35±0.30 and 0.46±0.12 individuals observed per minute) than in Little Tow (0.25±0.13 and 0.27±0.21 individuals observed per minute). Fish abundances were generally lower in the ROV data than in the video sled data. The fewer fish seen per minute in the ROV video undoubtedly reflected the slower speed of the ROV over the sea floor. The ROV covered much less area per minute than the video sled and the ROV's slow speed would also have allowed fish to avoid the vehicle. The much higher numbers of invertebrates seen in the ROV data were directly attributable to differences in the data collected. White sea stars (*Asterias vulgaris* and *Leptasterrias tenera*) and sand dollars (*Echinarachnius parma*) were counted in the ROV video, but not in the sled video. These organisms were by far the most abundant taxa seen in the areas surveyed and were too abundant to accurately count on the video sled film. When the sea stars and sand dollars were eliminated from the counts, the pattern was similar to that seen in the video sled data. Namely, invertebrates were more abundant in Mud Hole (0.55±0.24 and 0.62±0.28 individuals per minute) than in Little Tow (0.23±0.07 and 0.39±0.15 individuals per minute). Additionally, *Cancer* crabs dominated the invertebrate fauna in Mud Hole (Table 4.3-7 – ROV MH) and sea scallops dominated the invertebrate fauna in Little Tow (Table 4.3-8 – ROV LT).

The data collected from the ROV footage also highlighted within area differences in faunal distributions. With the exception of station 3C, fish were relatively abundant throughout Mud Hole (Figures 4.3-6 and 4.3-7 – ROV maps of MH). Fish were generally less abundant in Little Tow, and were exceptionally sparse in the sand waves at the southern end (Figures 4.3-8 and 4.3-9 – ROV maps of LT). A similar pattern was seen with *Cancer* crabs, which were generally more abundant in Mud Hole, but were patchily distributed. With the exception of station 1A, white sea stars were abundant throughout Mud Hole and in the northern half of Little Tow, and sparse in the southern end of Little Tow. In contrast, sand dollars were abundant only in the sand waves at the southern end of Little Tow. Sea scallops were more evenly distributed throughout Little Tow, and quite patchy in Mud Hole. The variability in faunal abundances *within* the two study sites appears to reflect the patchy nature of the habitats.

Video Evidence of the Effects of Trawling

Our experimental trawling was successful, with marks indicating bottom contact of the fishing gear clearly visible at all of the experimental lanes. Both side-scan and visual observations indicate that gear impacts were much more pronounced in the soft muddy sediments of Mud Hole. In the trawled Mud Hole lanes, the 350 kg steel doors of the *Andrea J*. ploughed through the sediments often creating 6-inch deep furrows (Plate 4.3-6). In contrast, in the sandier sediments of Little Tow the trawl door impacts were less apparent (2 to 3 inch deep tracks). Gear impacts were least visible in the sand waves at the southern end of Little Tow.

Effects on the bottom varied among the different components of the trawl (doors, sweep and ground cables). Furrows in the sediment created by trawl doors were frequently seen on either side of the centerline of experimental lanes. In contrast, the sediment at the center of the experimental lanes was frequently smoothed and shell material redistributed by repeated contact with the sweep of the trawl net (strung with 6 inch diameter rubber cookies) and/or the ground cables (strung with 2.5 inch diameter rubber cookies) (Plate 4.3-6, Photograph 4.3-1). Subtle striations were visible in these smoothed areas of sediment and were attributed to the rubber cookies. Other project related disturbances to the sediment that were visible on the video footage included scour areas from the vessel anchors, grab and grab frame marks, and video sled tracks.

Other than the obvious marks produced by the trawling gear, several subtler impacts were also observed. In muddy areas, the flocculent layer appeared to have been removed from the surface of the sediment, exposing more of the polychaete tubes commonly observed in these areas (Photograph 4.3-1). Scavengers such as rock crabs (*Cancer* sp.) and fish occasionally appeared to be attracted to the disturbance caused by the trawl doors (Plate 4.3-7). Also, with the passing of the underwater video gear some of the smaller fish such as red hake retreated into burrows, and invertebrates like sand anemones and mud anemones retreated into their tubes. Similar avoidance behavior is likely during the sweeping of a trawl net. In contrast, rock crabs were observed rearing up from the bottom and sea scallops swam away when the underwater video gear passed. Sea scallops and rock crabs were more readily caught during experimental trawling (Section 4.5). A few of the larger starfishes, such as sun stars and northern sea stars are also caught in the net. However the majority of the smaller sea stars and sand dollars observed on the video are not retained. In most cases in the flatter bottom areas, the sweep of the net probably passes over the top these animals. If these smaller invertebrates were kicked up into the net they would typically pass through the 6-inch mesh

Generally, lower megafaunal abundances were observed in the post-trawl surveys. The video sled data, which was collected several days after the experimental trawling (46 to 50 hours at Mud Hole and 85 to 89 hours at Little Tow), indicated that fish decreased by approximately one half in Mud Hole, from pre-trawl abundances of 2.02 individuals per minute to post-trawl abundances of 0.98 individuals per minute, and by approximately one fifth in Little Tow, from pre-trawl abundances of 0.92 individuals per minute to post-trawl abundances of 0.77 individuals per minute (Table 4.3-3). The abundance of invertebrates also declined similarly, with much of the decline being attributable to the removal of *Cancer* sp. (Tables 4.3-4 and 4.3-5).

A decline in abundance between the pre- and post trawl surveys was not as evident in data collected with the ROV, which was conducted within a day of experimental trawling (4 to 18 hours at Mud Hole and 16 to 18 hours at Little Tow). Fish abundances do not appear to be significantly different between the pre- and post trawling ROV surveys (Table 4.3-6). Part of this can be explained by the high initial variability of fish abundances, which ranged from 0.00 to 0.77 individuals per minute in Mud Hole and 0.08 to 0.63 individuals per minute in Little Tow. Fish abundances decreased at half of the experimental stations in Mud Hole and increased at the other half. In contrast, fish abundances decreased at all of the experimental stations in Little Tow. However, fish abundances also decreased at many of the control stations in both areas. When stations within lanes are looked at, in both areas fish abundances appeared to decrease more in the experimental lanes than in the control lanes (Tables 4.3-7 and 4.3-8). Pre- and post trawling differences in invertebrate abundances are only slightly more clear-cut (Table 4.3-6). Decreases occurred at 5 of the 6 experimental stations in Mud Hole and at all 6 experimental stations in Little Tow. However, decreases in invertebrate abundances were also observed at many of the control stations. Interestingly, fewer *Cancer* crabs were seen in both experimental and control lanes in each area (Tables 4.3-7 and 4.3-8). This species appeared to be actively attracted to the disturbance caused by the trawl gear. Part of this less pronounced difference in faunal abundances between pre- and post trawling in the ROV survey may reflect the patchy nature of the habitats. The spatial heterogeneity observed in the pre-trawling ROV survey could obscure the general trends observed in the video sled data.

When comparisons are made on a station-by-station basis it is obvious that post-trawling abundances were lower at some of the stations and not at others (Figures 4.3-6 through 4.3-9 – ROV maps). This pattern was observed at both experimental and control stations and again may attest to the patchy nature of these areas. A close examination of all of the stations does indicate that post-trawling decreases in abundances of fish and the dominant invertebrates were generally slightly more pronounced and consistent at the experimental stations.

The data collected from the towed video sled was also examined using hierarchical classification analysis, a multivariate pattern recognition technique. The dendrogram resulting from simple average linkage clustering of the Bray-Curtis similarity measure is shown in Figure 4.3-10. Lanes with similar fauna tend to cluster together and lanes with dissimilar fauna cluster further apart. The taxa responsible for most of the clustering structure are shown in Table 4.3-9. Prior to trawling all four of the Mud Hole lanes were faunally quite similar. These lanes had relatively high abundances of *Cancer* crabs and moderate to high abundances of flounder and ocean pout, with the two southern lanes (3 and 4) having the highest abundances of ocean pout. Prior to trawling Mud Hole also had the highest fish and invertebrate abundances. The two post-trawling Mud Hole lanes were faunally similar to each other, and clustered with pre-trawl Little Tow lane 1. All three of these lanes had moderate abundances of *Cancer* crabs. The other three pre-trawl Little Tow lanes (2, 3 and 4) clustered rather loosely with each other and with post-trawl Little Tow lane 1. All four lanes in this cluster had relatively high abundances of sea scallops. After experimental trawling the southern lane of Little Tow (Lane 3) was faunally dissimilar to the other lanes. This was a reflection of the relatively low abundances of both fish and invertebrates seen in this area. The community analysis shows that on a broad scale Mud Hole is relatively homogeneous faunally. Additionally, experimental trawling impacted the community similarly at both experimental lanes by decreasing the number of *Cancer* crabs and fish. Little Tow was faunally more heterogeneous, as evidenced by the looser clustering of the lanes. Additionally, trawling appeared to impact the southern area of Little Tow the most by removing many of the fish and invertebrates.

4.3.2 Dredge survey results

Specimens collected post-trawling with a biological dredge in 10-minute tows at sampling stations along trawled and control lanes in Mud Hole and Little Tow are provide in Appendix F. These collections were made primarily for voucher specimens and to help further characterize some of the invertebrate species commonly found at the study sites. The white sea stars (*Asterias vulgaris* and *Leptasterrias tenera*) and sand dollars (*Echinarachnius parma*) were the most abundant invertebrates collected. These species are small enough to readily pass through or be passed over by the smooth bottom trawl net and liner. Species not otherwise noted from trawl tows or video included: various shrimp species and egg cases of skate and moon snails.

4.4 Benthic Results

Benthic data and grab coordinates are provided in Appendix G. Benthic fauna comparisons were made based on species richness, densities of the 5 to 10 dominant species, and community composition. Species richness was analyzed by direct numerical comparisons of the numbers of species and by diversity analyses using the Shannon-Weiner and Simpson diversity indices. Finally community analyses were conducted using cluster analysis to identify affinities or discrepancies among groups of sites and species associations.

Some 260 marine benthic invertebrate species were identified in the samples from Mud Hole and Little Tow**.** The fauna was both diverse and abundant and typical of that seen in other areas in Massachusetts Bay. Species composition and distribution was influenced by sediments with some species more abundant in the fine sands with high levels of silt/clay and others more common in the medium to coarse sand sediments where there was very little silt/clay. Some species were exclusive to one sediment type.

The dominant species at 49 of the 67 grab samples analyzed was the small spionid polychaete, *Prionospio steenstrupi*. There were only four sites where this species was not among the dominant species. This species comprised from 20 to 46 percent of the total number of individuals at the sites where it was the numerical dominant (Table 4.4-1). It was also listed among the dominant species at all but four of the remaining sites. The ten numerically dominant species at each site are listed in Table 4.4-1. Summary statistics (e.g., average density, species richness and diversity) are reported in Table 4.4-2.

4.4.1 Existing benthic communities

In July 2001, the benthic grab samples in the lanes to be trawled at Mud Hole averaged 1374 individuals and 79 species (Table 4.4-2). In all but one sample *Prionospio steenstrupi* was the dominant organism. The only exception was at Station 3C where another spionid polychaete, *Dipolydora socialis,* was slightly more abundant (Table 4.4-1). This species was present in large numbers at most stations of the study. In all cases polychaetes comprised most of the dominant species. Some of the most common of these were *Spio limicola*, *Euchone incolor, Mediomastus californiensis, Maldane sarsi* and *Tharyx acutus*. The only non- polychaetes that appeared among the dominants were the small mollusks *Nucula delphinodonta* and *Thyasira gouldii*, the caprellid amphipod *Aeginina longicornis*, and the isopod *Edotea montosa*.

In the control lanes at Mud Hole, prior to trawling, grab samples averaged 1086 individuals and 76 species. These parameters were not significantly different from the trawl lanes. In all but two cases *Prionospio* was the dominant species. At stations 4A-1 and 4C-1 *Spio limicola* was more numerous. The remaining species listed as dominants in the control lanes were the same as at the proposed trawl lanes.

Species richness and densities were slightly lower in the sandier sediment of Little Tow. Samples from the lanes to be trawled averaged 1029 individuals and 70 species. In seven of the eight samples *Prionospio* was the dominant organism. At the middle station of Lane 3 the amphipod *Unciola inermis* was the dominant organism reflecting the coarser sediments found in this southern lane. *Prionospio* was reported in very low numbers (11). Many of the other dominant species were the same as those found at Mud Hole. Other polychaetes included *Spio limicola, Tharyx acutus, Spiophanes bombyx* and *Owenia fusiformis*. Non-polychaete species that were common were the small mollusks *Thyasira gouldii* and *Nucula delphinodonta,* and the isopod *Ptilanthura tenuis.*

The pre-trawl samples at the Little Tow control lanes had a mean density of 727 organisms per grab and richness of 63 species per grab. In all but one case *Prionospio* was the most abundant organism. At LT4B-2 *Unciola inermis* was dominant and *Prionospio* was rare. Faunal composition of the control lanes was very similar to that of the experimental lanes.

The main distinction between Little Tow and Mud Hole was in the proportions of certain species, relative densities and species richness. There was considerable overlap in the benthic infauna.

4.4.2 Effects of trawling on the benthic community

Grab samples ($0.04m^{2)}$ taken from trawled lanes at Mud Hole averaged 78 species and 1335 individuals. At five of the stations *Prionospio* was the numerical dominant, and *Spio limicola* was the most abundant organism at two other stations. The remaining dominant species were predominantly polychaetes such as *Dipolydora socialis, Euchone incolor, Mediomastus californiensis, Maldane sarsi, Tharyx acutus* and *Levinsia gracilis*. Non-polychaete species included the mollusks *Nucula delphinodonta* and *Thyasira gouldii*, the amphipod *Aeginina longicornis* and the isopod, *Ptilanthura tenuis*. All of the species listed as dominants in the pre-trawl survey were common or abundant in the post-trawl data.

Post-trawl samples from the control lanes at Mud Hole averaged 1283 individuals and 82 species. *Prionospio* was dominant in 7 of 10 samples. The most abundant species at the remaining sites were *Spio limicola* and *Dipolydora socialis*. Composition of the remaining dominant species was not significantly different from the trawled stations.

The average density in grab samples taken from experimentally trawled lanes in Little Tow was 1045 individuals and species richness was 67 organisms per sample. This was not significantly different from the pre-trawl results. *Prionospio* was dominant at all sites except LT3C-1P where the polychaete *Spiophanes bombyx* was more numerous. The remaining dominants were all species that had been reported in the pre-trawl samples.

Post-trawling the control lane samples of Little Tow averaged 844 individuals of 64 species. There were three samples where *Prionospio* was not the dominant species. In two cases *Spiophanes bombyx* was more numerous and in the third the tube dwelling amphipod *Unciola* was the most abundant organism. These are sites where sediments were of a coarser average grain size.

Faunal data was subjected to cluster analysis. A Bray and Curtis similarity coefficient was calculated for both untransformed and $\log_{10}$ transformed data and then subjected to group average sorting. In the dendrogram for the complete data set (Figure 4.4-1) there was some separation of Mud Hole and Little Tow samples but overall there was a fairly high degree of similarity among samples. The most distinct sites were Little Tow lanes 2, 3, and 4.

Many of the post-trawl samples were clustered with pre-trawl samples further suggesting that there were no significant differences in the benthic fauna before and after trawling.

Correlations based on Kendall's tau and Spearman's rho (Table 4.4-3) showed significant ($p < 0.001$) negative correlation between percentage of coarse sand in the sediment and species richness. In contrast, there was a significant positive correlation between the percent silt/clay and numbers of species.

For comparative purposes we have included some data from a long-term study in northwestern Massachusetts Bay. As part of an ongoing 301(h) waiver monitoring program, benthic samples have been collected at several sites outside Gloucester Harbor twice a year since September 1990. The environment is quite similar to that of our study area. Sediments range from 8 to 30 percent silt/clay with a predominance of very fine sands. The depth is slightly shallower and ranges from 30 to 35 meters. The sampling methods in both studies are very similar and based on the use of a 0.04m m^2 Ted Young grab with 0.5 mm sieving. With the exception of some samples collected in coarser sediments at the southern end of Little Tow, faunal composition in our study was very similar to that seen stations in the northwestern region of Massachusetts Bay over the last ten years. The dominant species at all sites near Gloucester was *Prionospio steenstrupi*. A variety of other spionids were also common as was the bivalve *Nucula delphinodonta*.

The stability of the benthic infauna over time is demonstrated in Figures 4.4-2 and 4.4-3 that show species richness and faunal densities at three stations over a period of ten years. Species richness in Figure 4.4-2 is based on the total number of species collected in 5 replicate grab samples at each site. While there are seasonal and annual variations, the number of species collected ranged from 88 to 134 per site with most values falling in the range of 100 to 120. Faunal densities have ranged from 10,875 to 49,875 organisms/m2. Most of the reported densities are in the range of from 20,000 to 40,000. In our study, faunal densities ranged from 18,190 to 34,347 organisms/ m2 which is within the range seen near Gloucester. At Mud Hole and Little Tow we collected an average of from 63.2 to 81.9 species per grab sample. Species accumulation over five grab samples in our data would result in similar, if not higher, species richness. Mud Hole might in fact have slightly higher species richness than the Gloucester sites due to the increased depth. The point of the comparison is that the fauna at Mud Hole and Little Tow during our study was quite similar to that found in a region of the northwestern portion of Massachusetts

Bay where there has been no trawling. The Gloucester data also gives an indication of the range of variation that might be seen both seasonally and annually.

The overall conclusions of the benthic data analysis are that while there were some differences between the faunal composition of Mud Hole and Little Tow there was considerable overlap. Faunal densities and species richness were somewhat lower in the sandier sediments of Little Tow. There were no significant differences in faunal parameters before and after trawling either at Mud Hole or Little Tow.

4.5 Fisheries Survey Results

4.5.1 Trawl Catch Results

To help interpret the mid-July 2001 catch results from the six tows along the trawl lanes 1 and 3 at Little Tow and Mud Hole, the data were expressed in a number of formats:

- Tables of catch by species in kg per tow and percent by weight;
- Graphs of catch data for select species and total catch to look for any trends with repetitive towing;
- Graphs of species densities (numbers of individuals per 1000 square meters) based on estimated numbers of major demersal species caught and the area swept during each tow; and
- Length frequency distributions for target species (winter flounder, yellowtail flounder and dogfish).

Table 4.5.1 is a master list of the species caught during trawling at the Mud Hole and Little Tow sites. Results are discussed by study site and lane below.

Little Tow catch weight was dominated by yellowtail, winter flounder, and spiny dogfish. Length frequency distributions for these species are provided on Figures 4.5-1, 4.5-2 and 4.5-3, respectively. Yellowtail and winter flounder ranged from about 10 to 40 cm in length with the mode about 25 cm. Spiny dogfish ranged from 60 to 90 cm in length with a mode of about 70 cm. Sculpins and crabs were also important components of the catch. Winter flounder were more than twice as abundant in trawl lane 1 than in lane 3 and yellowtail somewhat more abundant in lane 3, especially in the first tow (Tables 4.5-2 and 4.5-3). Downward trends in the abundance of the two flounders with trawling was similar in the two trawled lanes. In neither case did the combined catch rates of the other less abundant demersal finfish species (hakes, sea raven, congo eel, skates, monkfish, American plaice, 4-spot flounder, cod, sculpins, and windowpanes) show any trend. The catch rates of rock crabs declined during the first four tows in both lanes, then increased during the last two tows (Figure 4.5-4). Total catch rates declined downwards with towing effort in both lanes (Figure 4.5-5).

In *trawl lane 1*, the catch rate of yellowtail flounder declined steadily after the second tow, dropping by 72% by the sixth tow. Winter flounder declined in a very similar fashion (82%) after the first tow. Spiny dogfish also declined after the second tow. Rock crabs declined by 50% between the first and fourth tows, then increased slightly during the last two tows. There was no trend in the catch rate of other demersal finfish. The total catch rate declined by 56% between the second and fifth tows.

In *trawl lane 3* of Little Tow, the yellowtail catch rate declined by 58% between the first and third tows and only slightly after that. The winter flounder catch rate declined by 71% between the first and third tows, then nearly leveled off. There were no trends in the catch rates of dogfish or the other demersal finfish between the first and last tows. Crabs declined by 67% between the second and fourth tows, then increased during the last two tows, reaching a higher catch rate in the last tow than during the first tow. The total catch rate declined by 61% between the first and fifth tows.

Densities were dominated by yellowtail, winter flounder and sculpins. These three species accounted for 84% of the total bottom finfish density at Little Tow. Trends in the densities of the two flounders during successive tows mimicked the trends in catch rates. Sculpin density did not change with successive tows in either lane, but was higher in lane 3. There were no obvious trends in the densities of any of the other demersal finfish (Figures 4.5-6 and 4.5-7).

Mud Hole catch weight in lane 1 was dominated by mid-water species (spiny dogfish and Atlantic herring), with low catches of yellowtail and winter flounder. To the south in lane 3, winter flounder and crabs predominated and yellowtail catch rates were low. White and silver hake catch rates were high in lane 3 (Tables 4.5-4 and 4.5-5). Length frequency distributions for the target species, yellowtail and winter flounder and spiny dogfish are on Figures 4.5-8, 4.5-9, and 4.5-10, respectively. The size distribution of yellowtail flounder, winter flounder and spiny dogfish at Mud Hole was similar to that found at Little Tow.

There was no downward trend in the catches of winter flounder and yellowtail in lane 1, but in lane 3 both species declined between the first and the second or third tows, then their catch rates leveled off. Crab catch rates declined in lane 1, but not in lane 3. In both lanes, catch rates of the other demersal finfish species dropped abruptly after the first tow, then leveled off (Figure 4.5-11 and 4.5-12)

In *trawl lane 1* of Mud Hole, yellowtail flounder declined by 67% between the first and third tows, then increased by almost the same amount during the last three tows, reaching a value that was nearly the same as during the first tow. Winter flounder showed a similar pattern, dropping by 93% during the first three tows and then increasing just as dramatically during the fourth tow only to drop again to an intermediate level during the last two tows. Spiny dogfish catch rates declined after the second tow, then remained more or less the same during the last four tows. Crab catch rates dropped from over 10 kg/tow in the first tow to zero in the fourth, increased to 4.8 in the fifth tow, then dropped to zero again. Catch rates of the other demersal finfish were high in the first tow owing to the abundance of little skates, then dropped to low values during the last five tows. Total catch rates were higher during the first three tows than during the last three tows, declining by about 50% from the first to the last tow.

In *trawl lane 3* of Mud Hole, yellowtail catch rates declined by 90% between the first and third tows, then leveled off during the last three tows. Winter flounder followed the exact same pattern, declining to the same degree between the first and third tows before leveling off. Dogfish catch rates remained nearly constant during the first five tows, then increased sharply in the last tow. Crabs increased in abundance by 58% during the first four tows, then dropped during tows 5 and 6 to about the same point where they started out. The trajectory in catch rates for the other demersal finfish was very similar to what was observed in lane 1, except that white and silver hake accounted for the high catch rates in the first tow, not little skate. The total catch rate declined by 67% between the first and third tows, then leveled off.

There were high densities of winter flounder and silver hake in the first tow in lane 3, otherwise there were no noticeable differences in the density of individual species with successive tows at Mud Hole. Five species – yellowtail, winter flounder, sculpins, white hake, and silver hake – accounted for 85% of the total bottom finfish density at this location (Figure 4.5-13).

There were some clear differences in the abundance and species composition of the catch in the two study sites, and in the trends that were observed during the six tows made at the two sites. Yellowtail flounder were considerably more abundant at Little Tow and winter flounder were slightly more abundant at the Mud Hole. Habitat suitability for winter flounder is high at Mud Hole and the northern portions of Little Tow given the water depth, fine sand/mud substrate and salinity (USFWS, 2001). Catch rates for dogfish, white hake, and silver hake were higher at Mud Hole and sculpins were more abundant at Little Tow. Catch rates of rock crabs were a little higher in the Mud Hole. Atlantic herring made up a large proportion of the catch at the Mud Hole, but very few were caught at Little Tow.

There were more similarities in the trends observed for the two dominant flounders and the crabs between the two trawl lanes at Little Tow than at Mud Hole. Catch rates for these species, and the total catch rate, declined very similarly in the two Little Tow trawl lanes, and also more consistently during the six tows made at this location. At Mud Hole, catch rates for the two flounders declined more rapidly during the first three tows in lane 3 than at Little Tow, then leveled off instead of continuing to decline as they did at Little Tow. However, in lane 1 at Mud Hole, catch rates of yellowtail and winter flounder increased in the later tows after dropping during the early tows. Crabs also followed very different patterns in the two lanes at Mud Hole, declining during the first four tows in lane 1 and increasing in lane 3.

A possible explanation for increases in catch rates with repetitive trawling is that scavengers such as crabs and certain fish species may be attracted to the trawled lanes due to the trawl's disturbance of the bottom and possible exposure of benthic food sources. Video footage taken several hours after trawling shows crabs, lobsters or fish in trawl furrows (see Plate 4.3-7). Despite the increases in catch for certain species in the latter tows at Mud Hole, there was an overall downward trend in the total catch rate in both Mud Hole lanes with more or less constant catches during the last three tows in lane 1 and during the last four tows in lane 3.

4.5.2 Flatfish Stomach Content Results

The purpose of assessing the stomach contents of the targeted bottom feeding fish, winter flounder and yellowtail flounder, was to:

- document the diets of these flatfish within the study sites considered Essential Fish Habitat (EFH);

- determine how the flatfish prey selection may relate to the benthic fauna; and

- explore the potential effects of repeated towing on consumption or diet.

Feeding by *yellowtail flounder* is restricted by small mouth size. Crustaceans and polychaetes found on the sediment surface constitute large components of the yellowtail flounder diet. Crustaceans comprise about one half the diet by weight for yellowtails above 5 cm in length, and polychaetes, other invertebrates and fish (e.g., capelin and sand lance) make up most of the remainder. Among crustaceans, amphipods are the largest diet component (Link et al., 2002).

Winter flounder are generalists that feed on any prey of suitable size encountered while foraging. Adults have little variation in diet with size. Mouth size is even more restrictive than in yellowtail. Polychaetes, crustaceans (amphipods and decapods) and mollusks (bivalves) are identified as important prey by percent incidence and weight for studies in the Gulf of Maine. Polychaetes were frequently the most important food item on a percent weight basis and in terms of numbers (Langton and Bowman 1981). Cnidaria have also been found to be an important component of the adult winter flounder diet (Langton and Bowman 1981). Other food items include fish eggs, small fish and vegetation (nearshore).

The size ranges of the targeted flatfish from which stomachs were collected in this trawl study were similar between species and study sites, about 20 to 40 cm. Stomachs of yellowtail and winter flounder adults from initial tows, the 3rd tow (or in some cases 2nd) and 6th tows were sorted into broad taxonomic categories; annelida, crustacea, molluscs, other invertebrates and unidentifiable partly digested material (Table 4.5-6). Total stomach volume was summed, and average stomach volumes along with the percent of each prey category (by volume) were calculated for each species and tow event.

Average stomach volume varied about five fold, however, the range of stomach volumes was similar for the flatfish species (0.6 - 3.5 ml winter flounder, 0.6 - 3.0 ml yellowtail) and study sites (Figures 4.5-14 and 4.5-15). A substantial portion of the flatfish stomachs, approximately one half by volume, was comprised of unidentifiable well digested material. Of the remainder, in winter flounder stomachs from the first tow at Mud Hole and Little Tow prey proportions (by volume) were similar; about 40% annelids, 7% crustacea, 5% other invertebrates, and <1% mollusks. Winter flounder had similar proportions of prey in Mud Hole for subsequent tows, however, at Little Tow there was a trend for an increase in % crustacea with tow event (Figures 4.5-16 to 4.5-19). Similarly, for yellowtail flounder collected on the first tow, of the identifiable stomach contents primarily annelids were consumed (35% by volume), then crustacea 6%, and other invertebrates 1%. Like winter flounder, fish from subsequent tows at Little Tow, had an increase in percent of the stomach volume attributable to crustacea (Figures 4.5-20 to 4.5-23).

Ranked prey abundance in winter and yellowtail flounder stomachs by tow event is provided in Table 4.5-7a for Mud Hole and Table 4.5-7b for Little Tow. Interpretation of this ranking of prey abundance in stomach samples may be somewhat confounded by stomach volume and the number of stomachs that made up a sample. At the Mud Hole site winter flounder stomachs contained 48 prey taxa and yellowtail flounder 51 taxa. Similarly at Little Tow, winter flounder stomachs contained 39 prey taxa and yellowtail flounder 45 taxa. Overall there were 58 prey taxa identified indicating considerable overlap in the organisms eaten by the two species. Of these, 28 were annelids, 23 were crustaceans, and the remainder was classified as other, which included organisms such as mud anemones, ribbon worms, peanut worms, brittle stars, and sea stars. The percent of total prey taxa that were annelids, crustaceans and other invertebrates was similar for the two flatfish species.

The majority of observed prey items for the flatfish were classified as “infrequent” (5 to 30) or “rare” (<5). In other words, the winter flounder and yellowtail flounder were generalists tending to eat a few of a wide variety of organisms. Species eaten consistently and that were “abundant” (>100) and “common” (30 to 100) in stomach samples of winter flounder and yellowtail flounder were polychaetes in the ampharetidae, maldanids, and spionids; and caprellid amphipods.

Fish stomach contents in the initial tows reflected the benthic fauna identified in the grab samples. Small spionid polychaetes, especially *Prionospio steenstrupi*, were either common or abundant in fish stomachs in both species and were the numerically dominant organisms in the quantitative benthic samples. The aorid amphipod, *Unciola*, which was a dominant species in the sandier sediments of the study area, was consistently found as infrequent to common in flatfish stomach samples from Little Tow. *Aeginina longicornis* (the dominant caprellid amphipod) was also among the top ten benthic organisms numerically and was a preferred prey item by both species especially in Little Tow where it was more abundant. At Little Tow both flatfish species have an increase in crustacean consumption by the sixth tow. In addition, the volume and numbers of caprellids, and perhaps aroids, appeared to be greater in the stomachs (relative to other fauna) than found in benthic grab samples. *Aeginina longicornis* tends to be attached to epifaunal species like sponges and hydroids and in the interstices of sandy substrates. Thus, it may be more susceptible to gear disturbance than obligate infaunal species and become more available to predators. Aorid and caprellid amphipods were more frequently in the top ten species numerically in post trawl grabs. *Maldane sarsi* the dominant maldanid or bamboo worm is found in muddy sand and was more abundant in the Mud Hole benthos. Study video showed that the maldanid tubes extrude from the sediment and appeared to be more exposed after trawling, and therefore, potentially more susceptible to grazing by the flatfish. The anterior ends of these worms were frequently found in the flatfish stomachs. Ampharetid polychaetes were not among the more abundant species in the benthos numerically, however, they were one of the more numerous species in the flatfish stomachs suggesting some selectivity by the flatfish or else greater accessibility of these prey. Winter flounder may be able to select for larger polychaetes compared to yellowtail flounder. A larger polychaete about 2.5 inches long, *Pherusa affinis* or common broom worm (Flabelligeridae), although only infrequent to rare in winter flounder stomachs, at times made up a large percentage of the stomach volume. This species was absent or only rare in yellowtail stomachs.

Classification analysis of ranked prey abundances of the fish stomach contents was used to aid in the assessment of differences between study sites, flatfish species and level of trawling effort. The analysis was performed using BioDiversity Pro software (NHM & SAMS, 1997), with the Bray-Curtis measure as the similarity index and simple averaging as the clustering strategy.

Three clusters (numbered 1 through 3 on Figure 4.5-24) and one outlier were formed based on *classification analysis of the ranked prey abundances*. The first two clusters separate mainly by fish species, with cluster 1 mainly consisting of yellowtail flounder from both areas and cluster 2 mainly consisting of winter flounder from both areas. The 3rd cluster consists of both winter and yellowtail flounder from Little Tow. Further subgroups within clusters separate mainly by site and lane. Tow intensity appeared to be a lesser determinant of cluster structure. One outlier that has a low similarity to the other samples was the yellowtail stomachs from the 1st tow at Mud Hole Lane 3. The clustering structure suggests that *prey selection and location influenced the diet of flounder more than trawl intensity.*

Table 4.5-8 shows the dominant prey species responsible for most of the clustering structure and their distribution in the fish stomach samples. The fish stomachs in cluster 1, six samples of yellowtail flounder from both sites and two samples of winter flounder from Mud Hole Lane 3, all contained a high abundance (>100) of *spionid polychaetes*.

In contrast, the stomachs in the remaining two clusters, most of the winter flounder and a few yellowtail samples, contained fewer spionids. Spionids were common (30 to 100) in the yellowtail and winter flounder stomachs in group 2a and, with one exception, infrequent to rare in the other stomachs.

Cluster 3 consists of three Little Tow samples that contained common to abundant caparellid amphipods (skeleton shrimp) and ampharetid polychaetes. The outlier sample, yellowtail from the initial tow at Mud Hole Lane 1, was relatively depauperate containing only a few individuals of a number of species.

The six dominant prey taxa include four polychaetes and two amphipods (Table 4.5-8), were eaten by both species, but a few selective differences were noted. High abundances of spionid polychaetes were usually found in yellowtail stomachs. Spionids were generally much less abundant in the stomachs of winter flounder. In contrast, maldanid polychaetes (bamboo worms) were most abundant in winter flounder stomachs from Mud Hole. Ampharetid polychaetes were common in half of the samples and abundant only in the winter flounder sample from the initial tow at Little Tow Lane 3. In contrast, the aorid amphipod *Unciola* was only found in common abundances in the stomachs of yellowtail flounder, and were absent to infrequent in the stomachs of winter flounder.

Caparellid amphipods were abundant in the stomachs of both species from the last tow at Little Tow Lane 1, and common in approximately half of the other stomach samples.

Table 4.5-9 shows the changes in cluster group designation, and relative abundance of the top ten prey species, in the fish stomachs over time as the lanes were trawled. Spionids were one of the dominant prey species in yellowtail flounder in both areas and under differing trawling intensities. However, there did appear to be a shift towards higher abundances of some of the secondary prey species with increased trawling intensity. This was most pronounced in the yellowtail collected from Mud Hole Lane 1 and Little Tow Lane 3, which showed an increase in the number of species in the common category, but the trend can also be seen in the other samples. The abundance of ampharetid polychaetes and *Unciola* (amphipods) did appear to increase in yellowtail stomachs with increased trawling. This suggests that *with trawling some species may be more at risk to predation.*

Winter flounder showed some differences in diet between the two study areas. Spionids, maldanids, ampharetids, and caprellid amphipods were important components (>30 individuals per sample) of the diet of winter flounder in Mud Hole, but only two of these taxa, caprellids and ampharetids, were important in Little Tow. As was found in yellowtail flounder, there appeared to be a slight shift toward higher abundances of some secondary prey taxa with increased trawling. Caprellid amphipods and ampharetid polychaetes are examples of these taxa. Interestingly, while the abundance of *Unciola* increased in the diet of yellowtail flounder with trawling, it did not increase in the diet of winter flounder.

5.0 SUMMARY

In 2000, NOAA/NMFS funded Boat Kathleen A. Mirarchi, Inc.'s cooperative research proposal to conduct *Near Term Observations of the Effects of Smooth Bottom Net Trawl Fishing Gear on the Seabed.* In June and July 2001, following preliminary literature review and planning, the project team of fishermen and scientists characterized the generally soft substrate sea floor at approximately 130 ft of water in a heavily trawled area (Mud Hole) and a lightly trawled area (Little Tow) off Scituate, MA. The sea floor was surveyed before and after *six repetitive passes* with smooth bottom net trawl gear. The smooth bottom trawl used in our study is designed to hug the bottom and is a typical rig used in areas of mud and sand to catch flatfish. Parameters examined were the sea floor visual characteristics, water column characteristics, fish and bycatch, the stomach contents of select commercial bottom fish, and benthic infaunal and epifaunal communities. Tools successfully used to characterize the sites and elucidate trawling effects included: side-scan sonar, Hypack navigation software, precision single beam echosounder, remotely operated vehicle (ROV), video sled, benthic dredge, a conductivity, depth, oxygen and turbidity sensor (CTD), Ted Young modified ponar benthic grab, and a net liner during trawling. Similar to other recent studies our project indicates that the *immediate impacts* of the net sweep and other ground gear (excluding the heavy doors) on the benthic ecosystem is not great (NE Region Essential Fish habitat Steering Committee Oct 2001, Johnson 2002).

Near Term Effects of Trawling on Water Column Characteristics
The Little Tow study site was 10 to 15 ft shallower than Mud Hole. This difference in depth appears to result in more frequent and dramatic reworking of the sediment by wind, wave and tidal turbulence in Little Tow. CTD profiles did not show significant changes in water column characteristics of Mud Hole or Little Tow before and after trawling down to 100 ft. Casts closer to the bottom would likely have shown a near bottom turbid zone immediately following the trawling.

Near Term Effects of Trawling on Geophysical Characteristics
Gear impacts were more visible in the softer sediment of Mud Hole compared to the predominantly medium sand of Little Tow. Trawl doors caused deep furrows and ridges that attracted rock crabs and lobsters. Video observations indicated that untrawled seabed especially in Mud Hole had a hummocky appearance while recently trawled seabed was generally smoother at times with polychaete tubes exposed. The coarser Little Tow bottom was more variable and the physical impacts of the trawling were less visible.

Near Term Effects of Trawling on the Macrobenthic Community
Both sites had diverse macrobenthic communities and were similar in richness and abundance to untrawled sites studied in 30 m of water off Gloucester, MA. The difference in bottom substrate between the sites resulted in some differences in benthic fauna. *Prionospio steenstrupi* a polychaete was dominant in the finer sediments of Mud Hole and Little Tow, and *Unicola inermis* an amphipod was dominant in the sands of Little Tow. There was no difference in infaunal density, richness or composition following six passes of the smooth bottom trawl. There was a positive correlation of species richness with % silt/clay and a negative correlation of richness with % coarse sand.

Near Term Effects of Trawling on the Fish Community

The dominant bottom fish at Mud Hole and Little Tow were yellowtail and winter flounder. Dominant bycatch included dogfish, rock crabs and skate. There was a trend for flounder catch to decline with trawling. The stomach contents of the flatfish reflected the benthic infaunal community composition. The dominant prey item for yellowtail and winter flounder was the dominant spionid polychaete. Both flatfish showed some preferential selection for amphipods post-trawling.

Conclusion and Project Expansion

- The most significant impacts observed on soft bottom habitat at Mud Hole and Little Tow were those on the physical habitat by the trawl doors. These were more visible in the lower energy finer grained Mud Hole site compared to the slightly shallower more high energy environment of Little Tow. More subtle smoothing of the bottom was observed with the sweep. Some resuspension of sediment may be occurring based on shifts in grain size.

- The most immediate biological effect was the direct removal of large epibenthic organisms by the otter trawl particularly rock crabs and flatfish.

- Less obvious effects were the apparent exposure of polychaete worm tubes (Maldanidae) with the sweep of the net, potentially increasing their vulnerability to predation. Fish stomach analyses also suggest that amphipods become more available to predation by flatfish with increasing trawl intensity.

- No significant immediate impacts of otter trawling six times with a smooth bottom trawl net gear on benthic macrofaunal community was detected for the fine to medium sand habitats of our sites in Massachusetts Bay. The dominant species was the polychaete, *Prionospio steenstrupi*.

- The habitat of the study sites especially Little Tow are naturally dynamic and show changes in bottom characteristics irrespective of trawling activity. It is likely that the impacts of trawling on the infaunal benthic communities at Little Tow in particularly, and also Mud Hole are comparable in magnitude to these natural disturbances. This assertion may not hold true for trawl door furrows as these features, although a small portion of the impacted bottom were probably not adequately sampled.

- An on-going NOAA/NMFS funded extension of work at these study sites looks at the cumulative impacts of chronic trawling and temporal changes in these habitats over several months during 2002. The dynamic nature of the bottom sediment at Little Tow became quite apparent following a northeaster in the fall of 2002 when the bottom became completely reworked and covered by sand waves. Sediment Profile Imaging and a video grab camera were added for more fine-grained imaging.

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